PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 4 **:**
F02D 41/34, 41/14

A1

(11) International Publication Number: **WO 90/02874**

(43) International Publication Date: 22 March 1990 (22.03.90)

(21) International Application Number: PCT/EP88/00824

(22) International Filing Date: 10 September 1988 (10.09.88)

(71) Applicant *(for all designated States except US):* ROBERT BOSCH GMBH [DE/DE]; P.O. Box 10 60 50, D-7000 Stuttgart 10 (DE).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)* **:** HEIM, Hans [DE/DE]; Weidenbrunnen 91B, D-7000 Stuttgart 50 (DE). KLEIN, Hans [DE/DE]; Gartenstr. 28, D-7147 Eberdingen-Hochdorf (DE). HOMEYER, Manfred [DE/DE]; Fliederweg 9, D-7145 Markgröningen (DE).

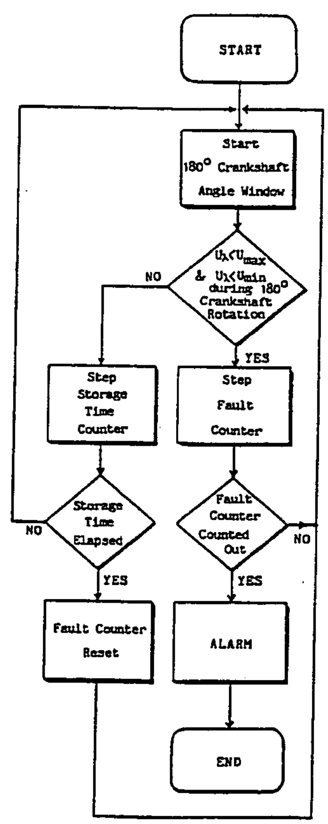
(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), FR (European patent), GB (European patent), IT (European patent), JP, KR, LU (European patent), NL (European patent), SE (European patent), US.

Published
With international search report.

(54) Title: ENGINE MISFIRE DETECTION AND ENGINE EXHAUST SYSTEMS

(57) Abstract

Misfire is detected in an internal combustion engine by monitoring the voltage (u_λ) of a lambda sensor disposed in the exhaust system upstream of a catalyser. This voltage is either compared with the voltge of another lambda sensor downstream of the catalyser or is processed, in the case of lămbda control, to detect troughs in the sensor voltage (u_λ). The phase relationship between the sensor voltage fluctuations and the engine timing identifies when the gases exhausted from a misfiring cylinder reach the lambda sensor. Knowing the expected gas travel time in relation to TDC, the misfiring cylinder is identified and the fuel injection to the misfiring cylinder can be terminated. This prevents unburnt fuel/air mixture from reaching the catalyser where it would combust and overheat the catalyser.



DESCRIPTION

ENGINE MISFIRE DETECTION AND ENGINE EXHAUST SYSTEMS

The present invention relates to a method of detecting misfire in a multi-cylinder internal combustion engine and to an apparatus for protecting an exhaust system of a multi-cylinder internal combustion engine, which exhaust system includes a catalyser.

It is known that exhaust gas catalysers and even the exhaust manifolds of internal combustion engines can be damaged or destroyed due to overheating. The danger of overheating arises in the event of a misfire, that is to say, the fuel/air mixture in one or more of the combustion chambers fails to ignite through faulty ignition. The uncombusted mixture when it reaches the catalyser whose working temperature is around 550°C is immediately ignited, rapidly heating the catalyser to a temperature at which the catalyst is destroyed. There is even the danger of the motor vehicle in which the engine is installed being set alight.

It is an object of the invention to provide a method and apparatus whereby faulty combustion or misfire can be immediately identified so that steps can be taken to prevent consequential overheating of the exhaust system, particularly of the catalyser.

Advantages of the Invention

These disadvantages are avoided by the method claimed in claim 1 and the apparatus claimed in claim 5. Not only is a misfire promptly detected through the oxygen content of the uncombusted gases leaving the engine, but measures can be taken to enable the faultily operating cylinder or cylinder group to be identified. In the case of petrol injection individual to the cylinder or the cylinder groups, the feeding of

further fuel to the misfiring combustion chamber can be prevented.

Further advantageous features of the invention are mentioned in the dependant claims.

Drawings

The invention is further described, by way of example, with reference to the accompanying drawings, in which:-

Fig. 1 is a diagrammatic representation of a four stroke internal combustion engine whose exhaust system contains a catalyser, fitted with lambda sensors in accordance with one embodiment of the invention;

Fig. 2 is a graph showing the output voltages of the lambda sensors;

Fig. 3 is a schematic circuit diagram of an electronic fuel injection system operable with lambda control in accordance with another embodiment of the invention;

Fig. 4 is a series of graphs relating to the embodiment of Fig. 3;

Fig. 5 is a logic diagram relating to one mode of operation of the embodiment of Fig. 3;

Fig. 6 is a series of graphs relating to the mode of operation of Fig. 5;

Fig. 7 is a logic diagram relating to an alternative mode of operation;

Fig. 8 is a graph showing the use of window discriminators; and

Fig. 9 is a diagram explaining the expected gas travel time.

Description of the Preferred Embodiment

Referring first to Fig. 1, a four-stroke petrol engine 10 for a vehicle has an exhaust system 12 containing at least one silencer 14 and an exhaust gas catalyser 16. The catalyser 16 is so disposed in the exhaust system that it runs at about 550°C, this being

the optimum temperature for catalysing the reduction of nitrogen oxide and the simultaneous oxidation of carbon monoxide and hydrocarbons, using up any residual oxygen in the exhaust gases.

Should there be a misfire in one of the engine cylinders, the uncombusted gases exhausted from that cylinder are caused to ignite in the catalyser. This causes the catalyser to heat up rapidly to a temperature at which the expensive catalyst is destroyed and there is a danger of the vehicle itself being set on fire, unless appropriate counter measures are taken.

According to the embodiment of Fig. 1, lambda sensors 18 and 20 are fitted in the exhaust system 12 upstream and downstream of the catalyser 16. The lambda sensors comprise a solid electrolyte and, as is well known, they deliver an output voltage which is dependant upon the residual oxygen content of the exhaust gases. The sensor voltages are shown very diagrammatically in Fig. 2. The output voltage u_1 of the upstream sensor 18 fluctuates slightly in synchronism with the exhaust strokes of the engine cylinder. On the other hand, residual oxygen is consumed in the catalyser 16 so that the output voltage u_2 of the downstream sensor 20 is substantially constant. Assuming the fuel/air mixture fed to the engine is in stoichiometric relationship or slightly lean, the average of the slightly rippling voltage u_1 is about the same as the voltage u_2.

In Fig. 2, it is assumed that one cylinder commences to misfire so that uncombusted fuel and air reach the upstream sensor 18 and the oxygen in the air causes a sudden drop in the voltage u_1. On the other hand, the fuel and oxygen are combusted in the catalyser 16 so that the output voltage u_2 of the downstream sensor 20 does not fall and it may even rise slightly.

To detect the occurrance of the sudden change in u_2-u_1, the outputs of the sensors are connected to a comparator 22 which delivers an output signal S when the voltage u_2-u_1 exceeds a predetermined value Δu. To reduce the likelihood of the fluctuations in the voltage u_1 triggering a false alarm, a smoothing circuit 24 can be arranged between the sensor 18 and the comparator 22.

The alarm signal s can be used to trigger an audible and/or visible alarm or to stop or restrict the fuel supply to the engine. If the misfiring cylinder can be identified, in the case of an internal combustion engine with petrol injection, the fuel supply to the faulty cylinder can be cut off by holding the respective injection valve closed. One way of detecting the faulty cylinder is to provide, instead of a single upstream sensor 18, several separate sensors in respective branch tracts of the exhaust system leading from the engine exhaust valves. The output of voltage of each such sensor is then compared with that of the downstream sensor.

In the case of an engine fitted with lambda control, in which the injected fuel quantity is adjusted in response to the air number λ of the exhaust gases as measured by the upstream sensor 18, the unconsumed oxygen in the event of a misfire and the consequent lowering of the output voltage u_1 cause the lambda control to regulate the engine to a leaner mixture so that the undulating output voltage u_2 then climbs back substantially to its previous value, as shown, in the event that the engine is not immediately stopped.

Fig. 3 shows an electronic fuel injection system for a four-stroke, four cylinder internal combustion engine having electronically controlled fuel injection and ignition systems. The four injection valves 26,28,30,32 (shown

diagrammatically) are opened and closed in timed relation to the crankshaft rotation under the control of a computer 34 and via end stage amplifiers 36. The injection valves 26-32 are individual to the four cylinders of the engine in that they inject the fuel into the engine inlet manifold branches adjacent the respective engine inlet valves. The computer 34 also controls the four spark plugs 38,40,42 and 44 (shown diagrammatically) via an ignition coil and distributor 46.

The computer 34 controls the injection valves 26-32 and the ignition trigger voltages suppled to the ignition coil 46 in accordance with operating parameters to provide the optimum injected fuel quantities, injection timing and ignition timing in conventional manner. The operating parameters include a reference pulse BM_1 inlet pressure p (vacuum), load L (pedal position), engine speed n, the air number λ, as measured by a lambda sensor in the engine exhaust system, and engine cooling water temperature T. The reference pulses BM are obtained in timed relation to rotation of the crankshaft and are for synchronisation purposes.

During normal running, the engine operates with lambda control and the lambda sensor (like the sensor 18 of Fig. 1) is arranged upstream of a catalyser in the exhaust gas system of the engine. Lambda control is control in accordance with the composition of the exhaust gases, and in particular, upon the oxygen content of the exhaust gases, whereby the fuel/air ratio is that which provides for optimum combustion, i.e., close to stoichiometric and minimum pollutants in the exhaust gases reaching the catalyser.

Fig. 4 shows at A the output of the lambda sensor and at B, the instants of ignition of the individual cylinders so that the timed relationship between the changes in the measured air number λ and the individual combustion operations can be seen. In normal operation as seen at the left of Fig. 4, the air number λ fluctuates between two extremes in accordance with on-off control by the servo loop forming part of the electronic control. In other words, a high air number $\lambda>1$ denotes a lean mixture whereby the fuel injection system operates to increase the injected fuel quantity until the air number $\lambda<1$ whereupon the injected fuel quantity is decreased. Each on-off fluctuation lasts for several, e.g., six, revolutions of the crankshaft.

At the instant T_1, one cylinder starts to misfire and in Fig. 4 continues to do so at every working stroke. The result is that the lambda sensor or oxygen sensor erroneously measures that the mixture is, on average, too lean so that the computer 34 operates to increase the injected fuel quantity until the lambda sensor again indicates an average air number $\lambda=1$, as shown in Fig. 4 by curve C. However, because of the now over-rich mixture and the unconverted oxygen from the misfiring cylinder, the output of the lambda sensor exhibits a sudden dip once for every two revolutions of the crankshaft as shown at the right-hand side of Fig. 4. To detect this situation, the output of the lambda probe is evaluated in a misfire detector 48 as will now be described.

In the simplest version, the output voltage u_λ of the lambda sensor is fed to a window discriminator to ascertain whether the voltage u_λ both rises above an upper threshold u_{max} and falls below a lower threshold w_{min} within 720° of crankshaft rotation. If it does,

a pulse is sent to a misfire counter, whose count is shown at curve D in Fig. 4. When the counter has counted, say eight misfires an alarm signal s is delivered.

If it is desired to identify the misfiring cylinder the window discriminator extends over 180° crankshaft angle, once for each cylinder, the cylinders being identified by the ignition trigger pulses and it is checked whether the sensor u_λ voltage first falls below the upper threshold u_{max} and then below the lower threshold u_{min} within each 180° window. If it does, a counting pulse is delivered to a respective counter and when the counter is counted out, a fault signal s is delivered to indicate an alarm and to which cylinder it relates. The fault signal s can be used in this case to inhibit the fuel injection signal to the respective injection valve by interrupting the corresponding output from the computer 34 of the end stage amplifier 36.

Spurious misfires are not harmful to the catalyser and it is desirable to prevent the misfire detector 48 from responding to misfiring at spaced random intervals. For this purpose, a storage time counter is also used, as shown in Fig. 5. For each cylinder, it is checked whether within the respective window of 180° crankshaft angle $u_\lambda < u_{max}$ and $u_\lambda < u_{min}$. If it does, a stepping pulse is applied to the fault counter. If it does not, a stepping pulse is applied to the storage time counter. Once the fault counter is counted out, the alarm signal s is delivered. However, should the storage time counter be counted out before the fault counter has been counted out, both counters are re-set. In other words if fewer than the number of misfires needed to count out the fault counter take place within the count-out period of the storage time counter, no fault is indicated.

The total count of each of the two counters can be adjusted to suit the operating conditions of the engine. Thus, for each counter, an empirically determined characteristic can be stored in the computer 34 to determine in accordance with, say engine speed n and engine load L, the number of misfires to be counted in the fault counter to trigger the alarm signal s and the number of crankshaft revolutions without misfire to be counted in the storage time counter before detected misfires are to be disregarded.

Fig. 6 illustrates this operation further. Curve A is the output voltage u_λ of the lambda sensor. It can be seen that the output is not as regular as Fig. 4(A) would suggest but the overall pattern of Fig. 4(A) is perceptible in Fig. 6(A). Curve B in Fig. 6 represents synchronising pulses obtained from the ignition system. Curve C represents the count of the fault counter. It can be seen that, following the start of misfiring at T_1, the sensor voltage u_λ falls below u_{max} = 110mV and then below u_{min} = 50mV to step the fault counter on 1. Over the following four working cycles (2x4=8 revolutions), the sensor voltage u_λ does not rise above u_{max} so that it cannot fall through the upper threshold to step the fault counter further and the latter is then re-set by the storage time counter timing out (counting out). The fault counter is then counted to 2 before being re-set. However, the effect of the lambda control then becomes apparent and the sensor voltage u_λ rises to significant values between the troughs and the fault counter is rapidly counted out to trigger the alarm at T_2. Curve D shows that the catalyser temperature only rises a few tens of degrees before the alarm is triggered. Fig. 6 assumes that no counter-measures are taken after the alarm is triggered or otherwise

the sensor voltage u_λ would not follow the course shown after T_2.

Another possibility is for the amplitude of the fluctuations in the output voltage u_λ of the lambda sensor to be measured in window discriminators within a corresponding 180° crankshaft angle for each cylinder. Should the difference between the highest and lowest values of the sensor voltage u_λ exceed a value predetermined in accordance with engine speed and/or load, a misfire signal is applied to a fault counter as described above. Also, as described above, the fault counter can be re-set in the absence of any further misfire signals within a predetermined, possible speed and/or load dependant interval. This is shown further in Fig. 7.

Since it takes time for the gases exhausted from a misfiring cylinder to reach the lambda sensor, the gas travel time must be taken into account in order to identify a misfiring cylinder by reference to the sensor output voltage and the ignition trigger pulses. Fig. 8 shows how the uncombusted exhaust gases from a misfiring cylinder can be identified by the lambda sensor. For a four cylinder, four stroke engine, the working cycle of 720° crankshaft angle is divided into four windows of 180° each. The window in which the falling flank of the sensor voltage u_λ crosses the upper and lower threshold corresponds to the uncombusted gases. Therefore, to ascertain the cylinder from which these gases came, it is necessary to delay the ignition pulses by the time taken for the working stroke of a cylinder to take place and the time taken for the gases to travel through the exhaust tract as far as the lambda sensor. Fig. 9 shows the gas travel time measured from the TDC of the misfiring cylinder. It is typically 560° crankshaft angle but does vary

according to engine operating parameters. Thus, the signals identifying the cylinders must be delayed by this gas travel time before correlating them with the misfire signal obtained from the lambda probe. Whilst mention is made above of using the ignition trigger signals as cylinder identification signals, inasmuch as the ignition trigger signal is close to TDC, this is not essential. It is possible to obtain cylinder identification signals in other ways, e.g., by dividing the interval between successive reference marks BM by the number of cylinders as shown in Fig. 9.

The expected gas travel time can be derived from an empirically determined characteristic field which is stored in the computer and which gives the expected gas travel time in dependence on engine operating characteristics, such as engine speed n and/or engine load L.

....

CLAIMS

1. Method of detecting misfire in a multi-cylinder internal combustion engine, characterised in that the output voltage of a lambda sensor in the exhaust system is monitored and is compared with a reference voltage, and a departure of the difference between the sensor and reference voltages from an expected value is signalled as a misfire in at least one of the cylinders.

2. Method according to claim 1 for an internal combustion engine whose exhaust system contains a catalyser, characterised in that the outputs of two lambda sensors arranged respectively upstream and downstream of the catalyser are compared and an increase in the difference between the output voltages of the two lambda sensors is taken as signalling a misfire in at least one cylinder.

3. Method according to claim 1, for an internal combustion engine equipped with a lambda control system, characterised in that fluctuations in the output voltage of the lambda sensor of the lambda control system are monitored and, if these fluctuations exceed a reference amplitude or cross a reference threshold, this is taken as signalling a misfire in at least one cylinder.

4. Method according to claim 3, characterised in that the instant of a fluctuation in the output voltage of the lambda sensor outside a threshold is compared with the instant of a reference mark (BM) indicative of a predetermined angular position of the crankshaft and the time difference between these instants is used to determine which cylinder has misfired, taking into account the expected time for the exhaust gases to travel from the engine exhaust valve to the lambda sensor.

5. Apparatus for protecting an exhaust system of a multi-cylinder internal combustion engine, which exhaust system includes a catalyser, characterised in that a comparing device is provided for comparing the output voltage of a lambda sensor disposed upstream of the catalyser with a reference value not normally reached and an output signal of the comparing device, indicative of a misfire is applied to means whereby uncombusted exhaust gases are prevented from reaching the catalyser.

6. Apparatus according to claim 5, characterised in that a second lambda sensor is disposed downstream of the catalyser and the difference between the output voltages of the lambda sensors is compared in a comparator with a reference threshold.

7. Apparatus according to claim 5, for an internal combustion engine equipped with a lambda control system, characterised in that a device is provided for monitoring fluctuations in the output voltage of the lambda sensor within a working cycle of the engine.

8. Apparatus according to claim 7, characterised in that the troughs in the output voltage (u_λ) of the lambda probe are detected to detect a misfire.

9. Apparatus according to claim 8, characterised in that the misfires are counted in a fault counter and an alarm signal (s) is provided when the fault counter is counted out.

10. Apparatus according to claim 9, characterised in that a storage time counter is provided and counts the time elapsed between detected misfires and both counters are re-set in the event of the storage time counter being counted out.

11. Apparatus according to claim 9 or 10, characterised in that the count-out time of either or both of the counters can be adjusted in dependence upon operating parameters of the engine.

12. Apparatus according to claim 11, characterised in that either or both counters are adjusted in accordance with a stored characteristic field.

13. Apparatus according to any of claims 8 to 12, characterised in that the troughs of the output voltage are detected by ascertaining whether the output voltage (u_λ) fluctuates beyond an upper threshold (u_{max}) and a lower threshold (u_{min}) or fluctuates outside a predetermined amplitude at least within a working cycle of the engine.

14. Apparatus according to claim 13, characterised in that the fluctuations are measured within a window defined by the crankshaft angle for a working cycle divided by the number of cylinders to enable a misfiring cylinder to be identified.

15. Apparatus according to any of claims 7 to 14, characterised in that the expected gas travel time as measured between the TDC or ignition trigger pulses of a given cylinder and the instant at which the gases exhausted from the cylinder reach the lambda sensor is taken into account to identify a misfiring cylinder.

16. Apparatus according to claim 15, characterised in that a characteristic field is stored in the computer and gives the expected gas travel time in dependence upon at least one engine operating parameter.

....

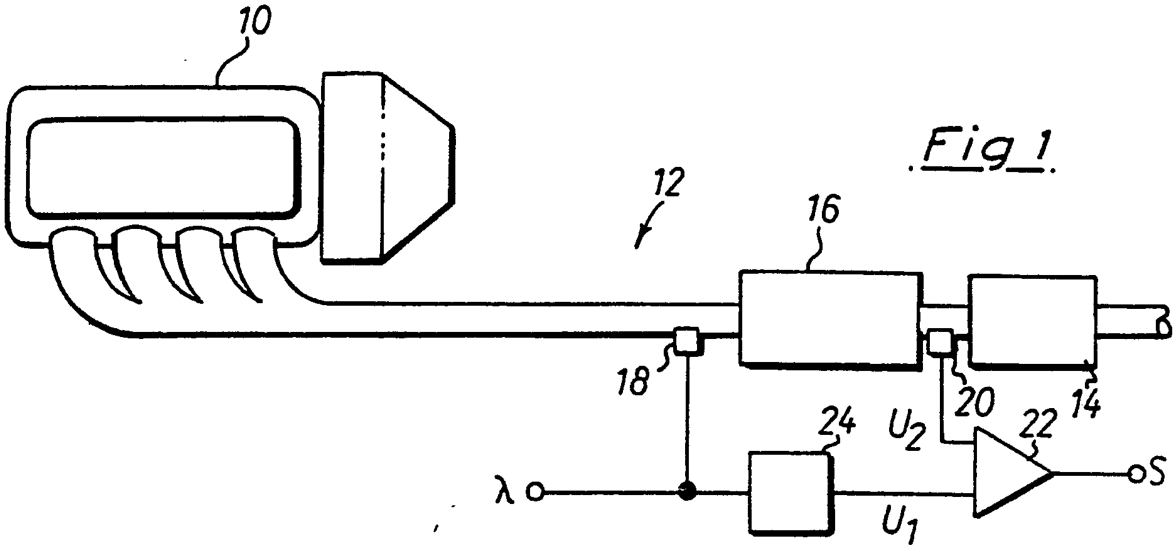


Fig 1

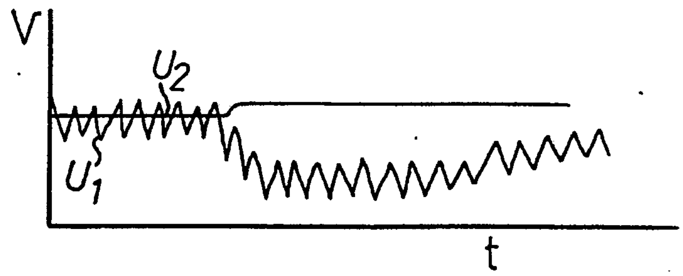


Fig 2

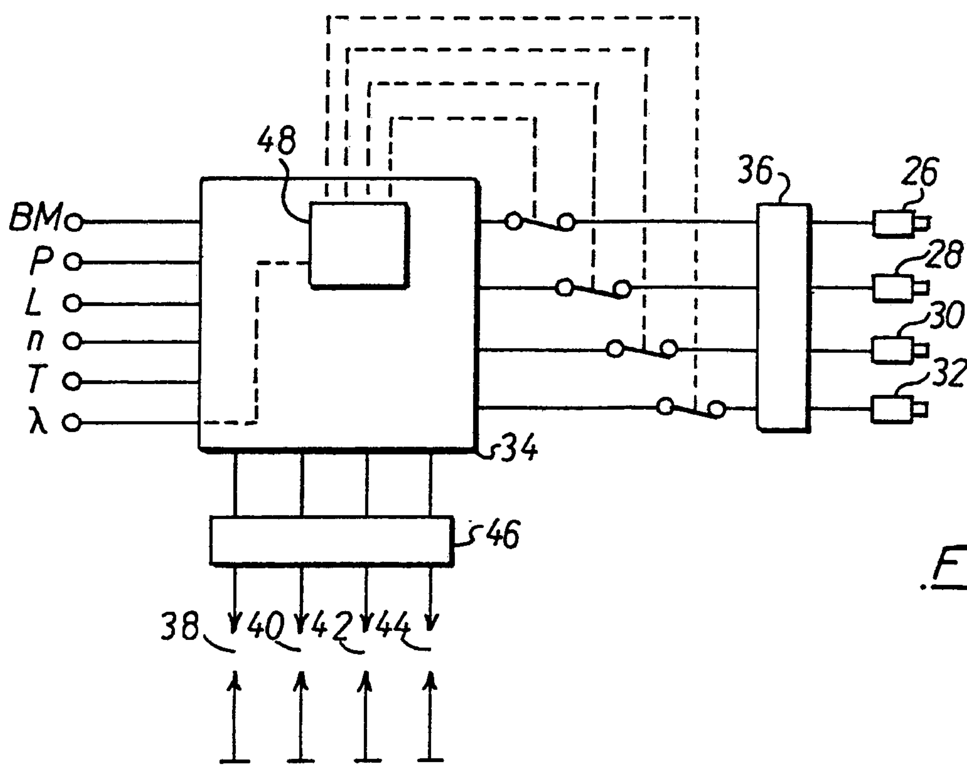


Fig 3

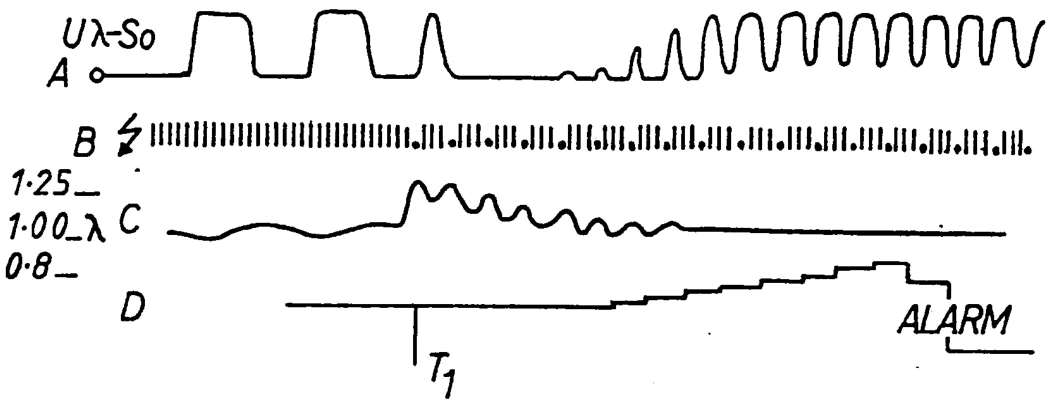


Fig 4

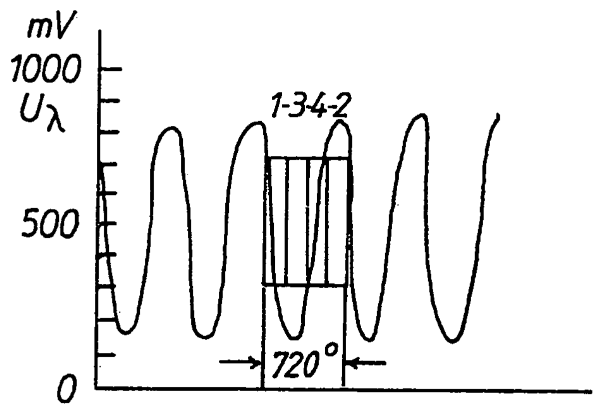


Fig 8

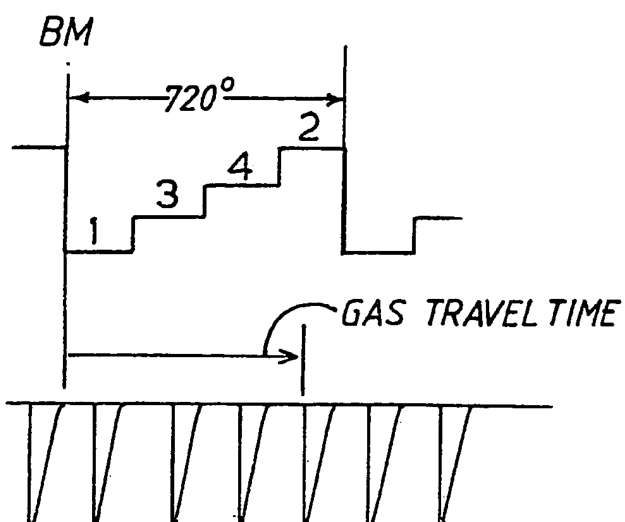


Fig 9

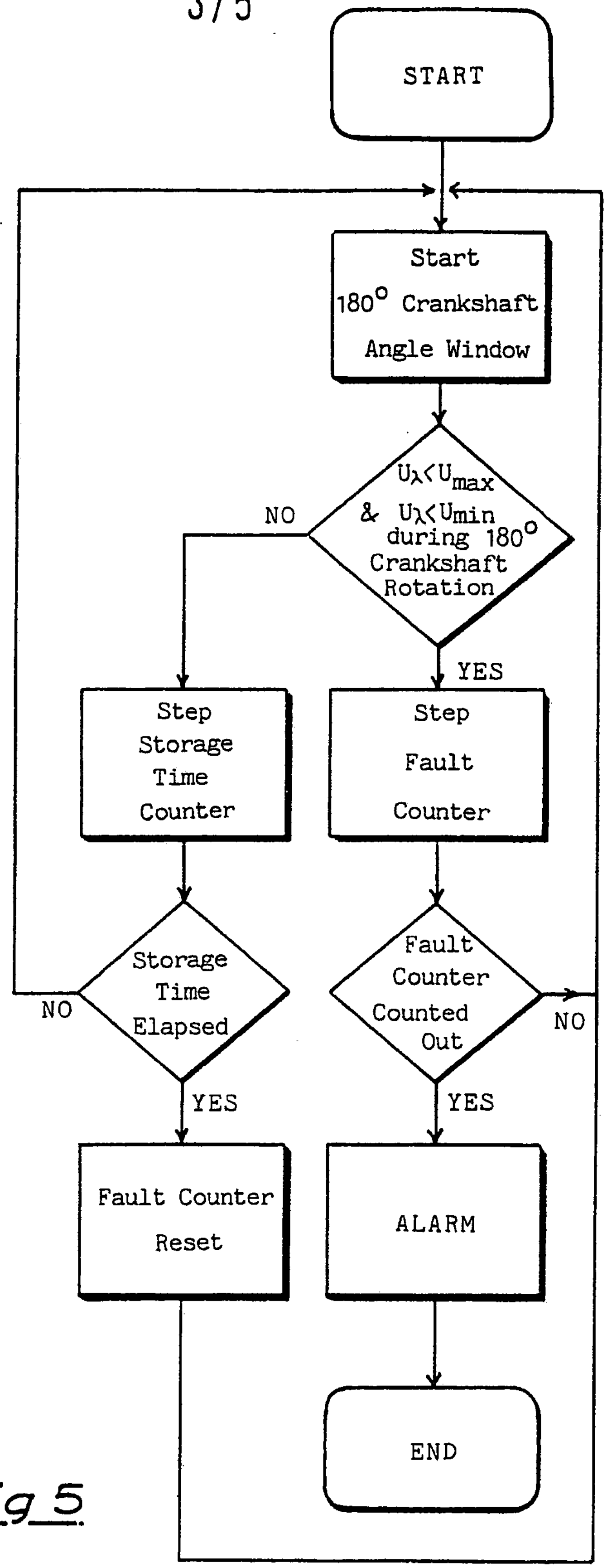

START
Start
180° Crankshaft
Angle Window
Uλ<Umax
& Uλ<Umin
during 180°
Crankshaft
Rotation
NO
YES
Step
Storage
Time
Counter
Step
Fault
Counter
Storage
Time
Elapsed
NO
YES
Fault
Counter
Counted
Out
NO
YES
Fault Counter
Reset
ALARM
END

Fig 5

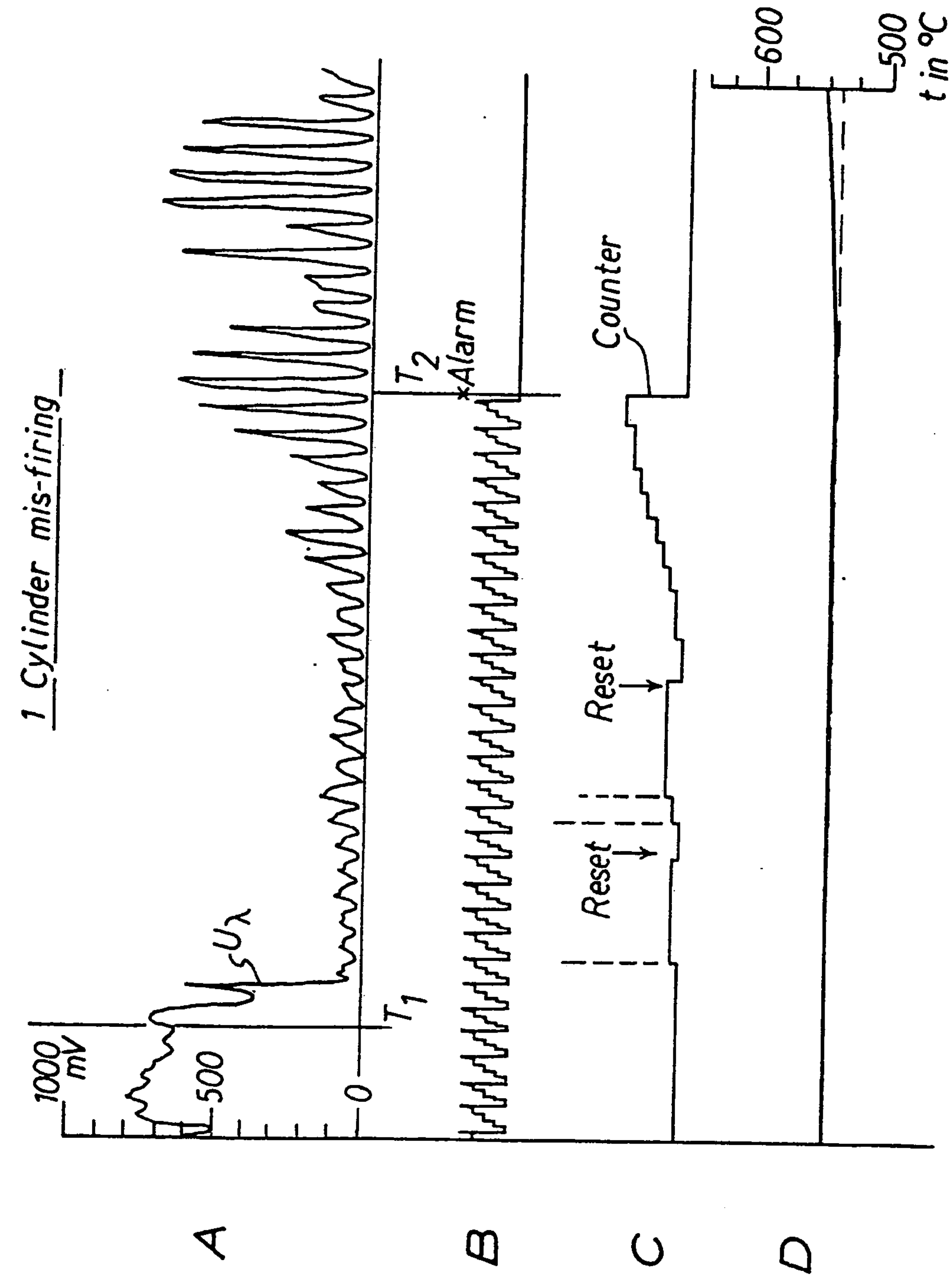

1 Cylinder mis-firing
1000 mV
500
0
Uλ
T1
T2
Alarm
Counter
Reset
Reset
600
500
t in °C
A
B
C
D

Fig 6

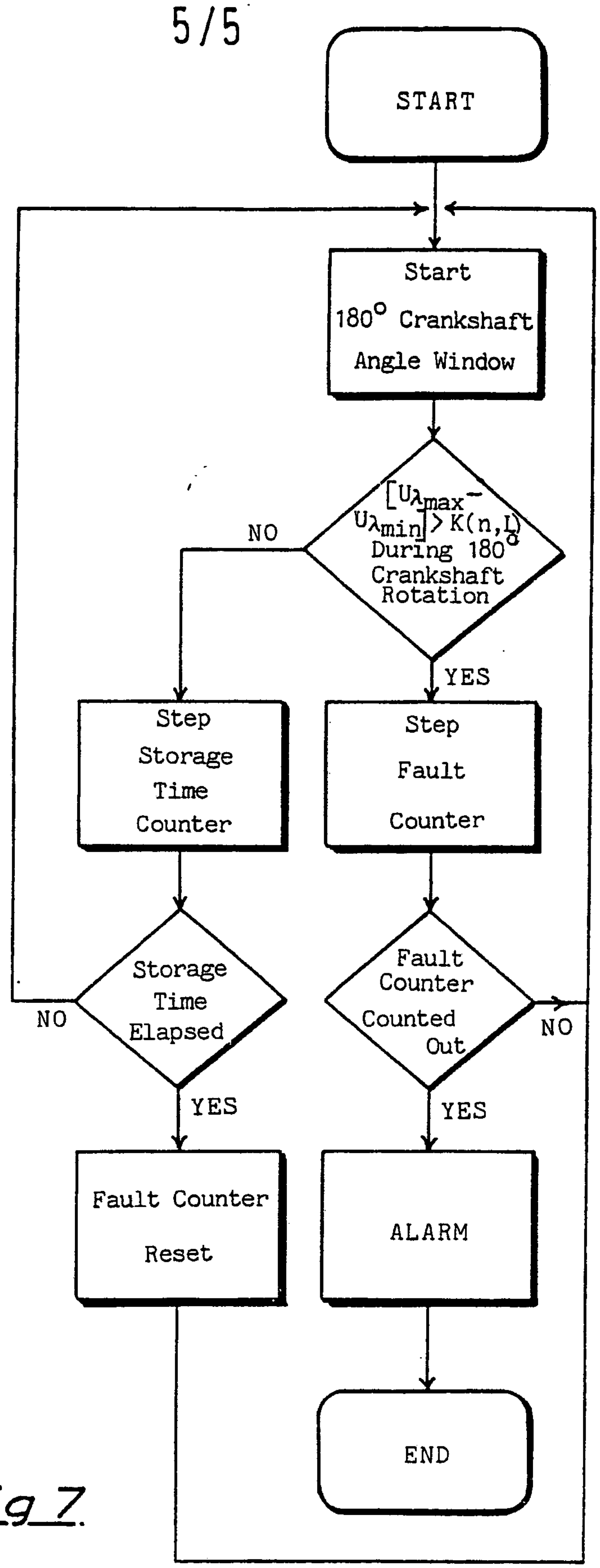

START
Start 180° Crankshaft Angle Window
[Uλmax-Uλmin] > K(n,L) During 180° Crankshaft Rotation
NO
YES
Step Storage Time Counter
Step Fault Counter
Storage Time Elapsed
NO
YES
Fault Counter Counted Out
NO
YES
Fault Counter Reset
ALARM
END

Fig 7

INTERNATIONAL SEARCH REPORT

International Application No PCT/EP 88/00824

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: F 02 D 41/34; F 02 D 41/14

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	F 02 D

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	US, A, 4030349 (BECKMAN IND.) 21 June 1977 see figures 3-5; column 1, line 62 - column 2, line 8; column 5, line 64 - column 6, line 68; column 7, line 67 - column 8, line 22 --	1,3,7
A	US, A, 3969932 (BOSCH) 20 July 1976 see figures 1,3; column 1, line 40 - column 3, line 58 --	1-3,6,7
A	US, A, 4696277 (NIPPON DENSO) 29 September 1987 see figures 1-10; column 1, lines 43-60; column 3, lines 23-33,56-66; column 4, line 54 - column 6, line 63; column 7, line 37 - column 8, line 48 --	1,3,4,7-10,13-15
A	DE, A, 3201372 (NISSAN) 5 August 1982 see page 8, line 7 - page 9, line 29; page 13, line 14 - page 18, line 10; ./.	1,3,4,7,8,13-16

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
3rd May 1989	09. 06. 89
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	P.C.G. VAN DER PUTTEN

Form PCT/ISA/210 (second sheet) (January 1985)

International Application No. PCT/EP 88/00824

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
	page 19, line 9 - page 23, line 17; figures 4-6B --	
A	DE, A, 3614535 (COMUNA) 5 November 1987 see column 1, line 62 - column 2, line 31; figures --------	1,5

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. EP 8800824

SA 24133

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 01/06/89
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4030349	21-06-77	DE-A- 2736445	23-03-78
		FR-A,B 2362392	17-03-78
		GB-A- 1529547	25-10-78
		NL-A- 7708163	20-02-78
US-A- 3969932	20-07-76	DE-A- 2444334	25-03-76
		FR-A,B 2285517	16-04-76
		GB-A- 1469390	06-04-77
		JP-A- 51055818	17-05-76
		SE-B- 417998	27-04-81
		SE-A- 7510333	18-03-76
US-A- 4696277	29-09-87	JP-A- 62107252	18-05-87
DE-A- 3201372	05-08-82	None	
DE-A- 3614535	05-11-87	None	

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82